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ABSTRACT

GRADES OR AGES: Grade 13. SUBJECT MATTER: Physics. ORGANIZATICN AND PHYSICAL APPEARANCE: The guide is divided into two parts, each of which contains the same four units. The first part briefly describes each unit; the second part gives a detailed outline of each unit. The guide is offset printed and staple-bound with a soft cover. OBJECTIVES AND ACTIVITIES: General objectives for the course are discussed in introductions to each of the two parts. Each unit in the second part gives a detailed list of topics to be covered and makes suggestions for experiments. Suggestions are made for timing of units and sections for experiments. INSTRUCTIONAL MATERIALS: A three-page section at the end of the guide mentions several references and describes the textbook and laboratory guides to be used in the course. It also contains a list of films categorized by unit. STUDENT ASSESSMENT: It is suggested that teachers use as a guideline the tests prepared for PSSC physics. (RT)

ED048209

ONTARIO DEPARTMENT OF EDUCATION

CURRICULUM S.17C (1967)

PHYSICS
GRADE 13

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PART A

Course of Study

FOREWORD

Curriculum S.17C (1967) is based upon the work of the Physical Science Study Committee in the United States. The aims of this course are also the aims of the P.S.S.C. Physics course, namely, to present:

1. a conceptual framework of contemporary Physics

2. an illustration of how knowledge is acquired experimentally and woven into physical theory

3. an illustration of how theory in turn directs and illuminates experimentation

4. Physics, not as a static codification of physical ideas, but as an integrated picture of contemporary Physics – a purposeful mode of inquiry

The main theme in Curriculum S.17C (1967) is the wave-particle duality of radiation and matter. Since the content of each topic contributes to the development of the main theme, it has been necessary to omit many facets of Physics which have traditionally been included in courses of study at this level. Nevertheless, the course synthesizes a carefully developed, well-integrated story line which calls upon many of the classical and modern topics in Physics. The presentation culminates in an application of the wave and particle models of matter to a description of the hydrogen atom.

Fundamental to the philosophy of this course in Physics is reliance on the development of physical principles from experimental data, obtained wherever possible, from experiments which the student performs himself. These laboratory experiences are supplemented by films and textbooks in order to increase the opportunities for inductive reasoning. These three – the laboratory, the film, and the textbook – constitute the essential media through which the student learns how knowledge is acquired experimentally and woven into physical theory.

Since Mathematics is the language of Physics, mathematical tools such as functions, vectors, and graphs are used throughout the development of the story. Experimental data are analysed graphically in order to arrive at the mathematical function which neatly expresses the relationship existing between the physical properties under study.

Physical models of phenomena are developed, then modified, accepted, or rejected as they succeed or fail in describing various aspects of the phenomenon being studied.

The course has been designed to explore deeply a few of the most fundamental ideas of Physics. It aims at providing all students, whether or not they intend to continue the study of Physics, with an understanding of Physics as a continuing process by which men seek to understand the nature of the physical world.

UNIT I
TIME, SPACE, AND MOTION

1. Fundamentals of measurement
2. Functions
3. Motion along a straight line path
4. Motion in space

Unit I is a general introduction to the concepts of time and space. The measurement of time intervals has been selected as the primary area for students to study experimentally the vital role of measurement and the extension of our senses by instrumentation. Following the development of some necessary mathematical tools, the student will undertake a more detailed study of time and space through the topic of kinematics. Kinematics has been separated from dynamics, which forms the basis of Unit III, for three reasons: (i) to provide time for the kinematical ideas to mature before being used again in Unit III, where they are naturally reviewed, (ii) to create a clear distinction in the students' minds between ideas which are purely kinematical and those which involve dynamics, e.g., centripetal acceleration and centripetal force, (iii) to interrupt what many students consider to be a heavy load of formal subject matter when kinematics and dynamics are studied in sequence.

Throughout this study, pupils should learn the limitations of measurements and should understand that in calculations involving measured quantities, the accuracy of the result depends upon the accuracy of the individual measurements involved. While no attempt need be made to develop a set of rules regarding the accuracy of a calculated result, the class should discuss the idea that an acceptable result is one which is reasonable in terms of the measurements used in its calculation.

UNIT II
OPTICS AND WAVES

1. How light behaves
2. The particle model of light
3. Waves propagated in one dimension
4. Waves propagated in two dimensions
5. Interference
6. Light and the wave model

Unit II divides naturally into three main sections: (i) an accumulation of a body of facts regarding the behaviour of light, (ii) the consideration of a particle model for this behaviour, (iii) a thorough exploration of the behaviour of waves in order to provide the knowledge necessary for the consideration of a wave theory of light.

Unit II uses the study of light as a vehicle to show how physical models or theories are developed. An understanding of how scientific hypotheses grow out of and are confirmed or denied by experiment will give students early in the year a feeling for the structure of physics and scientific growth in general. Moreover, this procedure will be an excellent preparation for development of the theory of the structure of the atom in Unit IV. There is a further reason for studying light and waves before delving deeply into the mechanics of particles: students have more intuitive ideas about particle behaviour than about wave characteristics. Therefore it is necessary to establish early and strongly an awareness of the nature of waves. This sequence of considering a particle theory for light and then, after becoming familiar with the properties of waves, changing over to a wave model for light, should cause the students to be more responsive to the wave properties of matter particles introduced in Unit IV.

UNIT III
MECHANICS

1. Law of inertia and Newton's law
2. Motion in the Earth's gravitational field
3. Universal gravitation law and the solar system
4. Momentum and the conservation of momentum
5. Work and kinetic energy
6. Potential energy

Unit III deals with the dynamics of particles. This involves a study of force and mass, which leads naturally to development of the concepts of momentum and energy, and the related conservation laws. Emphasis is again placed on the fact that all the physical laws developed here are based on experimental observations. This should be particularly noted in the case of the law of conservation of momentum. At the stage where it is treated, Newton's "third law" has not yet been introduced. This is in sharp contrast to courses in which the conservation of momentum is treated as a deduction from Newton's "second" and "third" laws.

Unit III includes only material which contributes directly to the concepts in Unit IV. For instance, a good foundation in mechanics is required before one can define fundamental electrical units. A thorough treatment of the sections on gravitational force fields and gravitational potential energy *in general* will save much time in Unit IV when teaching electrical force fields and electrical potential energy with point charges.

UNIT IV
ELECTRICITY AND ATOMIC STRUCTURE

1. Electric forces and electric charges
2. Energy and motion of charges in electric fields
3. Electric field and electric potential
4. The electromagnetic spectrum
5. Rutherford's model of the atom
6. Photons
7. Matter waves
8. Energy levels
9. Energy levels of hydrogen

Unit IV deals with a quantitative consideration of the atomic structure of matter. The material has been selected on the assumption that the students understand the qualitative facts of electricity and atomic structure from earlier studies. The unit begins, therefore, with a quantitative study of electrical forces, which provides the necessary tools to look quantitatively at atomic structure. The wave kinematics from Unit II and the particle mechanics from Unit III are then used to arrive at the modern wave-mechanical description of both radiation and matter which is required for an understanding of the world of the atom. The unit and course end with an application of this concept of the wave-particle duality of nature to a detailed description of the hydrogen atom.

PART B

Curriculum Study Guide

FOREWORD

The purpose of this Curriculum Study Guide is to assist teachers with their presentation of Curriculum S.17C (1967), Physics, Grade 13. The Guide is intended to provide a set of suggestions relating to:

- **the implementation of course objectives**
- **the depth of treatment**
- **teaching aids and their use**

It is understood that suggestions in this Guide are offered only for optional use at the teacher's discretion.

IMPLEMENTATION OF COURSE OBJECTIVES

In order to achieve the objectives of the course stated in the foreword to Part A, the Physics teacher should tell at least part of the continuing story of Physics and communicate some appreciation for the structure of the subject, rather than just "cover the subject matter" of several seemingly unrelated fields. The teacher should constantly strive to:

(a) direct the attention of his students to the continuity of this course
(b) take every opportunity to give them an insight into scientific investigation
(c) encourage them to exercise their reasoning ability.

COURSE CONTINUITY

The main theme of this course is the wave-particle duality of radiation and matter. The course culminates in an application of the wave and particle models to a description of the structure of the hydrogen atom. The teacher needs to point out the purpose of each unit in developing this theme. This story-line approach integrates the many aspects of Physics introduced in the course. For example, acceleration plays an important role, not only in the kinematics of Unit I and the dynamics of Unit III, but also in the production of electromagnetic radiation referred to in Unit IV. Other recurring concepts worth tracing through the course may include the idea of using measuring instruments to extend the experimenter's senses, forces and their fields, vectors, physical models, momentum, energy and its transfer, interference, conservation, direct and inverse relations. While the story-line threads its way throughout the course, the student must be made aware that this is a story "to be continued." Its open-endedness is a vital characteristic.

SCIENTIFIC INVESTIGATION

Scientific investigation involves (i) the collection of data from observations of physical phenomena in the laboratory, (ii) the analysis of the data in an effort to express physical behaviour in mathematical form, and (iii) the search for explanations in terms of models, theories, and laws.

The Collection of Data

Wherever possible the student should obtain necessary data from experiments which he performs himself. In the section on the depth of treatment, these are identified as "student experiment(s)." In cases where the experiment is too involved, costly, or time consuming, the student should obtain the data from the textbook or a film. In general, however, he should not be expected to accept the validity of scientific principles without experimental justification.

In order that the conditions in the student laboratory parallel those in the physicist's, the teacher should give as few leading suggestions and instructions as possible. The student should be encouraged to discover. Naturally, the teacher should bear in mind that time does not permit unlimited use of the inquiry-discovery-discussion approach. The student should learn to use measuring instruments with care and to appreciate the limit of their precision. Above all, the student should realize that the experiment is not over when the observations are concluded. The data must be analysed mathematically before worthwhile conclusions can be drawn.

The Role of Mathematics

The data resulting from a quantitative experiment are usually presented first in tabular form. Secondly, the data becomes more meaningful when plotted graphically. The third step consists of the formation of a mathematical equation which expresses

the relation between the variables. Finally, the student must realize that the equation has physical meaning and application.

The topic of Functions in Unit I is designed to introduce the student to algebraic and graphical methods of expressing relationships between variables. He should be able to predict the shape of the graph if a simple function is given. In a few cases, he may be able to predict the function from the graph. In most cases, he will have to be taught to replot the data in order to obtain a straight line graph, from which he should then be able to state the functional relationship in a mathematical equation.

The student should also learn how to determine the effect on one variable when another related variable is changed. For example, he should know from $E_k = \frac{1}{2}mv^2$ that if the velocity of a given mass is doubled, its kinetic energy is quadrupled.

The above concepts concerning proportions are not necessarily a part of any Mathematics course taken previously, but many of the topics taught in Mathematics, particularly in Grade 13, have direct application to Physics. Among these are the slope of a tangent to a curve, and the scalar or dot product of two vectors. The teacher of Physics should be aware of these and other overlapping areas. Moreover, he should become familiar with the terminology of the new Mathematics, and use it in order to communicate effectively with his students.

The Search for Explanations

This course, particularly Unit II, should lead the student to appreciate what a theory is, what it does and what it does not do, and what the failure of a theory means. The teacher should point out that a theory involves making some guesses as to the explanation of observed phenomena, and then reasoning what the consequences of the guesses might be. A theory must include an explanation of facts already known. However, the theory may involve ideas which have not yet been tested. The predictions of a theory may be found to be false when checked experimentally, and in this sense the theory is said to fail. Yet occasionally, as the student finds in Unit II, it may be necessary to say that the theory is valid only in certain circumstances. Moreover, the student should be made to feel that the failure of a theory, rather than being a disaster, is often a milestone in the history of Physics.

Although a student may not develop a full appreciation of a law in Physics, he may at least be prevented from acquiring one common misconception. Events do not take place in a certain manner because a law says they should. Rather, the law is a summary of observed behaviour. Snell's law does not control the amount of refraction of light; it summarizes in a brief statement or formula, thousands of experimental observations.

REASONING ABILITY

This course should be taught in such a way as to provide the student with frequent opportunities to reason, rather than simply to memorize facts. While it may not be possible to increase the student's reasoning ability, it should be possible to develop the latent ability which he already possesses.

The structure of Physics and the nature of scientific investigation call for clear thinking. The interplay of facts, concepts, laws, and theories should be made relevant to the student. Wherever feasible, he should be permitted to discover facts for himself and to take part in class discussions following the laboratory work. It is not enough for the teacher to present the facts and then arbitrarily state the consequences.

Both inductive and deductive reasoning should play important roles in the study of Physics. In Unit III, four different experiments leading to the law of conservation of momentum are suggested. Each experiment can be approached from the aspect of inductive reasoning where the student discovers for himself the concept of conserved momentum in one situation, finds it in another, checks for it in a third, expects it in a fourth, and then asks, "Is momentum always conserved?" A good criterion of a student's deductive reasoning power is his ability to apply his knowledge to new and varied situations, constantly advancing to more complex applications.

DEPTH OF TREATMENT

This section of the Guide is intended to suggest an expanded version of the Course of Study. These suggestions are meant to act only as a general guide. The teacher should feel free to change the emphasis as he sees fit, but he should achieve a reasonable balance of laboratory work, mathematical analysis, class discussion, and problem solving. Time should not be wasted on unnecessary review of topics introduced in Grade 11. When they reach Grade 13, students should understand elementary ideas related to displacement, velocity, and acceleration in preparation for Unit I, to geometrical optics and wave phenomena for Unit II, Newton's laws for Unit III, and electricity for Unit IV. Suggested time allotments for the first three units have been chosen carefully to provide the required time for a satisfactory treatment of the fourth unit. Times listed for each of the sections within the units are stated merely as a guide to emphasis placed on the various sections, and may be considered flexible.

The emphasis on problem-solving in the various sections has been suggested by vertical lines drawn to the left of each topic. These lines are intended to show that problem-solving may be considered to fall into four categories:

Major emphasis on the quantitative aspects of the topic. This emphasis may be implemented by the assignment and discussion of a good number of suitable problems. Such topics are indicated by three vertical lines to the left.

Moderate emphasis on the quantitative aspects of the topic. Clarification of the topic by means of a few problems is recommended. Such topics are indicated by two vertical lines to the left.

Minor emphasis on the quantitative aspects of the topic. The treatment should include simple problems which provide a direct test of the student's understanding of the physical principles underlying a formula. Problems of this type involve changing one variable by a given factor and asking for the effect on a related variable. For example, "An astronaut has a weight of 800 newtons at the earth's surface. What does he weigh when he is at a distance of 4 earth radii from the earth's centre?" Topics which may receive such minor emphasis are indicated by one vertical line to the left.

No emphasis on the quantitative aspects of the topic. A qualitative treatment of these topics is considered to be adequate. These topics are indicated by the absence of vertical lines.

Details of the depth of treatment begin on the following page.

UNIT I

TIME, SPACE, AND MOTION

(total time approximately 6 weeks)

1. FUNDAMENTALS OF MEASUREMENT (probably 1 week)

(a) The concept of measurement as the counting of intervals
  (i) Measurement of time as the counting of unit time intervals
  (ii) Measurement of distance as the counting of unit space intervals

(b) Measurement of short time intervals
  (i) Multiple-flash pictures
  (ii) Hand stroboscope

(c) Student experiments to measure short time intervals using a hand stroboscope

(d) Standard form. (Power of ten notation)
  (i) The expression of large and small numbers using standard form
  (ii) The concept of the order of magnitude of physical quantities

2. FUNCTIONS (probably 1 week)

(a) The analysis of experimental data to determine the proportionality between two variables by graphical means to find a linear relationship

(b) The use of equations and graphs for expressing relationships among physical quantities involving:
  (i) Direct proportions
  (ii) Inverse proportions
  (iii) Power laws, both direct and inverse

(c) The uses and limitations of interpolation and extrapolation

3. MOTION ALONG A STRAIGHT LINE PATH (probably 2 weeks)

(a) The description of motion using position-time graphs
  (i) The slope of the line between two points on a position-time graph as the average velocity

$$v_{av} = \frac{\Delta x}{\Delta t}$$

  (ii) The slope of the tangent at a point on the position-time graph as the instantaneous velocity

$$v_{inst} = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

(b) The description of motion using velocity-time graphs
  (i) Displacement as the area under a velocity-time graph

(ii) Average and instantaneous accelerations as slopes of velocity-time graphs

$$a_{av} = \frac{\Delta v}{\Delta t}, \qquad a_{inst} = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t}$$

(c) Derivation of the following kinematic equations for constant acceleration using a velocity-time graph

$$v_f = v_i + at \qquad d = \frac{v_f + v_i}{2}.t$$

$$d = v_i t + \tfrac{1}{2}at^2 \qquad v_f^2 = v_i^2 + 2ad$$

(d) Student experiments to illustrate the concepts in sections 3(a) and 3(b)

4. MOTION IN SPACE (probably 2 weeks)

(a) Position vectors. Displacement as the change in position vector

(b) The addition and subtraction of vectors, and the multiplication of vectors by numbers and scalars

(c) The velocity vector

$$\vec{v}_{av} = \frac{\Delta \vec{x}}{\Delta t}, \qquad \vec{v}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t}$$

(d) The treatment of vector problems using components. The independence of mutually perpendicular components

(e) The constant acceleration vector. The analysis of projectile motion as an example of constant acceleration when the path is not linear

(f) Changing acceleration vectors

(i) Accelerations which change in magnitude only

(ii) Acceleration which changes in direction only, e.g., circular motion

(iii) Acceleration which changes in magnitude and direction

$$\vec{a}_{av} = \frac{\Delta \vec{v}}{\Delta t} \qquad \vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t}$$

(g) The effect of an acceleration component parallel to the velocity and of an acceleration component perpendicular to the velocity

UNIT II
OPTICS AND WAVES
(total time approximately 6 weeks)

1. HOW LIGHT BEHAVES (probably ½ week)

(a) Brief review of the behaviour of light with respect to:

(i) Sources

(ii) Speed of light in air and in a vacuum

(iii) Rectilinear propagation

(iv) Non-interaction of light beams

(v) The laws of reflection

(b) Brief review of refraction and extension to include Snell's law, that is

$$\frac{\sin\theta_1}{\sin\theta_2} = \text{a constant for a given boundary}$$

(c) Brief discussion of:

(i) Dispersion of white light by a prism

(ii) Diffraction as the bending of light around an obstacle

2. THE PARTICLE MODEL OF LIGHT (probably 1 week)

(a) The concept of a scientific model or theory

(b) Initial formation of the simple Particle Model postulating:

(i) Size and spacing of light "particles" to account for non-interaction of intersecting light beams

(ii) Velocities of light "particles" to account for rectilinear propagation

(c) Further development of the simple Particle Model postulating:

(i) Elasticity of particles and surfaces to account for the laws of reflection

(ii) Forces of interaction of particles with matter to account for refraction

(d) Successes of the simple Particle Model regarding:

(i) Propagation through a vacuum

(ii) Snell's law: $\frac{\sin\theta_1}{\sin\theta_2} = \text{a constant.}$

Student experiment to demonstrate Snell's law for particles

(iii) Absorption and heating

(e) Predictions of the simple Particle Model

(i) Light pressure

(ii) The inverse square law of intensities

(iii) Refraction: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_2}{v_1}$, as suggested by the experiment in 2(d)(ii)

(f) Failures of the simple Particle Model

(i) $\frac{\sin\theta_a}{\sin\theta_m} = \frac{c}{v_m}$ rather than $\frac{v_m}{c}$ as predicted

(ii) Partial reflection and transmission

(iii) Diffraction patterns

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3. WAVES PROPAGATED IN ONE DIMENSION (probably ½ week)

(a) Introduction to waves

A review of the concept of a wave as a disturbance that travels without transfer of material. An experimental study of the propagation of wave pulses to discover that:

(i) Wave velocity is constant in a uniform medium

(ii) Wave velocity depends on the nature of the medium

(iii) Wave velocity is independent of the pulse shape or size

(b) An experimental study of wave pulses in a linear medium to show:

(i) Non-interaction of wave pulses

(ii) Superposition of wave pulses

(iii) Reflection at a fixed and at a free end

(iv) Partial reflection and transmission at the boundary between two media

(c) A preliminary discussion of the suitability of the Wave Model for light

4. WAVES PROPAGATED IN TWO DIMENSIONS (probably 1½ weeks)

(a) Water wave pulses

(i) Student experiments to study the production and propagation of straight and circular wave pulses and the reflection of wave pulses from straight and curved barriers

(ii) A discussion of the results of these experiments as further support of the Wave Model for light

(b) Periodic waves

(i) A discussion of periodic waves: period, frequency, velocity, and wavelength; and their interrelationship as expressed by the equations

$$v = \frac{\lambda}{T} = f\lambda$$

(ii) A student experiment on the production of straight periodic waves and the measurement of frequencies and wavelengths of water waves

(c) Refraction and dispersion

(i) A student experiment to investigate the dependence of the speed and the wavelength of periodic water waves upon the depth of water

(ii) A student experiment on the refraction of straight water waves to discover

$$\frac{\sin\theta_1}{\sin\theta_2} = \text{a constant} = \frac{v_1}{v_2}$$

(iii) A demonstration of the dispersion of water waves

(iv) A discussion of the results of (i), (ii), and (iii) as further support for the Wave Model for light

(d) Diffraction

(i) A student experiment to investigate the diffraction of water waves as they pass through an opening or past a barrier. The dependence of this diffraction on the width of the opening or barrier and the wavelength of water waves

(ii) A discussion of the results of the above experiment as further support for the Wave Model for light

5. INTERFERENCE (probably 1 week)

(a) Interference of periodic waves

(i) A brief study of the interference of periodic waves in linear media to show the production of a series of nodes

(ii) A student experiment to observe the interference pattern produced by two periodic point sources in phase in a two-dimensional medium

(iii) A quantitative discussion of the interference pattern produced in the above experiment and the derivation of the following equations:

$$\text{Path difference} = (n - \tfrac{1}{2})\lambda = d\sin\theta_n = \frac{d}{L}x_n$$

(iv) A student experiment to check the relationships developed in (iii)

(b) Effect of phase.

A brief qualitative demonstration of the effect of the relative phases of the two point sources on interference patterns

6. LIGHT AND THE WAVE MODEL (probably 1½ weeks)

(a) Interference effects produced by a double slit

(i) The interference of light as predicted by the Wave Model

(ii) The experimental conditions that must be fulfilled in order to observe the predicted interference of light

(iii) The derivation of the equation: $\lambda = \frac{d}{L}\Delta x$

(iv) A student experiment to investigate the interference of light produced by a double slit

(v) Experimental determination of the wavelengths of red and blue light

(vi) The relation between the colour and the wavelength of light

(b) Interference effects produced by diffraction

(i) A student experiment to observe a single slit interference pattern

(ii) An explanation for the single slit interference pattern

(iii) Visual comparison of the interference patterns produced by single and double slits

(c) Interference effects produced by thin films

(i) Experimental discovery of the interference patterns produced when monochromatic light is incident on a thin soap film

(ii) Brief explanation of the pattern observed by reflected light. Explanation, in terms of phase inversion, of the dark area observed at the top of the film

(d) Successes of the Wave Model for light

(i) Rectilinear propagation

(ii) Reflection

(iii) Refraction: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2}$

(iv) Non-interaction of intersecting light beams

(v) Interference

(vi) Diffraction patterns

(vii) Dispersion

(viii) Phase inversion

(ix) Partial transmission and reflection at a boundary

(e) A failure of the Wave Model for light.
Propagation of light through a vacuum

UNIT III
MECHANICS
(total time approximately 8 weeks)

1. LAW OF INERTIA AND NEWTON'S LAW (probably 2 weeks)

(a) Introduction to dynamics

(i) The distinction between kinematics and dynamics

(ii) Brief discussion of pre-Galilean dynamics

(iii) Discussion of Galileo's thought experiments and Galileo's law of inertia (Newton's first law)

(b) An experimental development of Newton's law of motion

(i) A student experiment to discover how the velocity of a cart changes under the influence of a constant force and to discover the dependence of acceleration on force

(ii) Derivation from the experimental data of

$$F\triangle t \propto \triangle v$$

(iii) Inertial mass as the proportionality constant in $F\triangle t = m\triangle v$

(c) Inertial mass

(i) Inertial mass as the measure of an object's resistance to changes in motion

(ii) A comparison of inertial and gravitational mass

(d) Newton's law of motion (Newton's second law)

(i) $F = ma$

(ii) The newton as the unit of force

(iii) The vector addition of forces

(iv) The vector nature of Newton's law

$$\vec{F}\triangle t = m\triangle\vec{v}; \qquad \vec{F} = m\vec{a}$$

2. MOTION IN THE EARTH'S GRAVITATIONAL FIELD (probably 1 week)

(a) Weight and the gravitational field of the earth

(i) $\vec{g}$ as the proportionality factor between the earth's gravitational force and the gravitational mass
$\vec{F} = m\vec{g}$

(ii) The earth's gravitational field

(iii) The deduction that $\vec{a} = \vec{g}$ for a freely falling object

(iv) A brief discussion of terminal velocity

(b) The validity of Newton's law of motion when the force is constant but not parallel to the velocity, as demonstrated by projectile motion

(c) The validity of Newton's law of motion when the force is constant in magnitude but changing in direction, as demonstrated by circular motion

(i) A student experiment to discover the dependence of centripetal force on the frequency of revolution

(ii) Derivation of $F = \frac{mv^2}{R}$ and $\vec{F} = -\frac{4\pi^2 m\vec{R}}{T^2}$ and their application to earth satellites

3. UNIVERSAL GRAVITATION LAW AND THE SOLAR SYSTEM (probably ½ week)

(a) Introduction to the history of planetary systems

(i) A brief reference to the work of Copernicus and Brahe

(ii) A brief discussion of Kepler's laws

(b) Newton's analysis of the dynamical problems inherent in Kepler's laws

(i) Derivation of $F = \frac{GMm}{R^2}$

(ii) A comparison of the acceleration of the moon using $a = \frac{4\pi^2 R}{T^2}$ with the acceleration as calculated using Newton's gravitation law

4. MOMENTUM AND THE CONSERVATION OF MOMENTUM (probably 1½ weeks)

(a) The concepts of impulse and momentum

(i) The magnitude of an impulse as the area under a force-time graph for straight-line motion

(ii) Momentum as the product of mass and velocity

$$\vec{p} = m\vec{v}$$

(iii) The relationship between impulse and change in momentum

$$\vec{F}\Delta t = \Delta\vec{p}$$

(b) The law of conservation of momentum

(i) Experiments to investigate the momentum changes in an explosion and collisions in one dimension

(ii) A student experiment to verify the vector nature of the conservation of momentum in a two-dimensional collision using two bodies of equal mass

(iii) Discussion of momenta of various two-body interactions

(iv) Brief reference to the general nature of the law

(v) Derivation from $\Delta\vec{p}_1 = -\Delta\vec{p}_2$

of $\vec{F}_{2-1} = -\vec{F}_{1-2}$ (Newton's third law)

5. WORK AND KINETIC ENERGY (probably 1½ weeks)

(a) Work

(i) Work as a measure of energy transfer. The work done on an object is equal to the magnitude of the component of the force in the direction of motion times the distance moved

(ii) Work as the area under the force-position graph when the force is parallel to the displacement

(iii) The component of any force perpendicular to the displacement does no work

(b) Kinetic energy and its relation to work.

Derivation of $E_k = \frac{1}{2}mv^2$

(c) Analysis of elastic collisions

(i) Transfer of kinetic energy in elastic collision

(ii) Derivation of $\triangle E_k(\text{tot}) = F\triangle S$

(iii) Concept of an elastic collision as an interaction in which the force depends only on the separation

(iv) Further properties of an elastic interaction: at minimum separation, velocities are equal and the total kinetic energy is a minimum

(v) A qualitative demonstration to illustrate the transfer of kinetic energy during a slow collision

(d) Application of the conservation of momentum and the conservation of kinetic energy to simple collisions. The derivation and use of formulae resulting from the combination of the two conservation laws are not required.

6. POTENTIAL ENERGY (probably 1½ weeks)

(a) Stored energy in a stretched or compressed spring

(i) A student experiment to determine Hooke's law ($F = kx$)

(ii) Derivation of $U = \frac{1}{2}kx^2$

(iii) Discussion of the mechanical energy in a spring which obeys Hooke's law

(b) Conservation of mechanical energy in elastic interactions

$E = U + \frac{1}{2}mv^2$

(c) Gravitational potential energy near the surface of the earth

(i) Derivation of $\triangle U = mg\triangle h$

(ii) A student experiment to investigate the transfer of gravitational potential energy to potential energy of a stretched spring. Discuss the role of kinetic energy in this experiment

(d) Gravitational potential energy in general

The relationship $U_r = -\frac{GMm}{r}$

(e) Applications of the conservation of mechanical energy

(i) Binding energy

(ii) Escape energy and the escape velocity of satellites

(f) A brief discussion of the conservation of energy in general

UNIT IV
ELECTRICITY AND ATOMIC STRUCTURE
(total time approximately 8 weeks)

1. ELECTRIC FORCES AND ELECTRIC CHARGES (probably 1½ weeks)

(a) Coulomb's Law.
Experimental evidence leading to the relationship $F = \frac{kQq}{r^2}$

(b) Vector addition of electric forces

(c) Electric force fields.

The description and explanation in terms of electric force vectors of the electric fields created by:

(i) A single charged sphere

(ii) Two small oppositely charged spheres

(iii) Two oppositely charged plates

(d) The Millikan experiment

(i) Experimental evidence that the driving force is proportional to the terminal velocity ($v_o \propto F_d$)

(ii) Discussion of an experiment to discover if there is a natural unit of electric charge

(iii) Experimental evidence that F_d is inversely proportional to plate spacing; proportional to the number of batteries; and independent of the plate area

(iv) Discussion of a large scale Millikan experiment to determine the value of the constant of proportionality in Coulomb's Law

2. ENERGY AND MOTION OF CHARGES IN ELECTRIC FIELDS
(probably ½ week)

(a) A discussion of experiments to determine the mass of electrons and protons. Introduction to conservation of energy in electrical systems

(b) Electric current as the rate of flow of elementary charges

(c) The battery as an energy source

(i) Battery supplies a constant amount of energy per elementary charge

(ii) EMF ($\mathcal{E}$) as the energy supplied per elementary charge by the battery

(iii) Power supplied by a battery as $I\mathcal{E}$

3. ELECTRIC FIELD AND ELECTRIC POTENTIAL (probably 1 week)

(a) Electric field is the force per elementary charge acting on a positive charge.

$$\vec{E} = \frac{\vec{F}}{q}$$

(b) Electric potential energy for two point charges:

$$U_e = \frac{kqQ}{r}$$

Compare to: $U_r = -\frac{GmM}{r}$

(c) Electrical potential as the potential energy per positive elementary charge

(i) $V = \frac{U_e}{q}$

(ii) $V = \frac{kQ}{r}$ for a field created by a point change

(iii) Concept of poten al hills and wells

(d) Potential difference

(i) Definition of potential difference

(ii) Potential difference is independent of the path from initial to final position

(e) Definitions of the volt, coulomb, ampere, and electron volt

4. THE ELECTROMAGNETIC SPECTRUM (probably ½ week)

(a) Description of the electromagnetic spectrum showing the relative positions of the various types of radiation and the approximate ranges of wavelength and frequency

(b) Common properties of all electromagnetic radiation

(i) Speed in vacuo $= 3 \times 10^8$ m/sec.

(ii) Produced by accelerated charges

(c) Student observation of absorption and emission line spectra

(d) Absorption and emission line spectra as evidence that atoms emit and absorb discrete wavelengths rather than a continuous spectrum, and that the wavelengths emitted or absorbed are characteristic of the type of atom

5. RUTHERFORD'S MODEL OF THE ATOM (probably ½ week)

(a) A discussion of the qualitative scattering experiment as a first step in building the model

(b) A brief discussion of the quantitative scattering experiment as evidence that scattering is the result of a Coulomb force

(c) Description of Rutherford's model in the light of the preceding experiments

(d) A brief discussion of the use of scattering experiments to determine:

(i) Atomic number of atoms

(ii) An upper limit on the diameter of a nucleus

(e) Difficulties with Rutherford's classical atomic model

(i) Inexplicable deviations from Coulomb scattering

(ii) Predicted instability of atoms versus the known, observed stability

(iii) Predicted emission of continuous radiation by atoms versus the known emission of discrete characteristic wavelengths

6. PHOTONS (probably 1½ weeks)

(a) A discussion of a qualitative experiment with X-rays or ultraviolet light and small particles to indicate that light emission is quantized rather than continuous. Photon as a bundle of light energy

(b) A discussion of Taylor's experiment to show that normal interference effects still occur even when there is no more than one photon involved at a time

(c) The photoelectric effect

(i) A discussion of an experiment with a phototube to show that the number of electrons emitted is proportional to the number of photons, and that the wavelength of light photons determines whether or not electrons are emitted

(ii) A discussion of a quantitative experiment to show that the graph of maximum kinetic energy of emitted electrons versus the frequency of the incident light is linear; and that when the type of emitting surface is varied, only the intercepts change

(iii) Einstein's interpretation of the photoelectric effect

$$\text{Energy of photon} = h\nu = \frac{hc}{\lambda}$$

$$E_k = h\nu - B$$

(iv) The physical interpretation of $E_k = h\nu - B$

(d) Photon Mechanics: The Compton Effect

(i) Momentum of a photon:

$$p = \frac{h\nu}{c} = \frac{h}{\lambda}$$

(ii) A comparison of the formulae for the energy and momentum of a photon with those for a slow moving particle

For a photon: $E = h\nu$; $p = \frac{h}{\lambda}$; and $E = pc$

For a particle: $E_k = \frac{1}{2}mv^2$; $p = mv$; and $E_k = \frac{1}{2}pv$

(e) Particle-wave duality for electromagnetic radiation

(i) Discussion of the incompatibility of the two different models

(ii) Discussion of how to choose the appropriate model in a specific situation

7. MATTER WAVES (probably 1 week)

(a) A brief qualitative discussion of experiments which demonstrate the wave nature of particles

(i) Electron diffraction

(ii) Electron interference produced by a biprism

(iii) Interference of helium atoms

(iv) Interference of neutrons

These experiments are important only as evidence of the wave property of matter. Details of the experimental techniques are unnecessary.

(b) The de Broglie relationship for the wavelength of particles

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE_k}}$$

(c) Particle-wave duality for matter

(i) Discussion of the incompatibility of the two different models

(ii) Discussion of how to choose the appropriate model in a specific situation

(d) Radiation and matter

(i) Similarities and differences between radiation and matter

(ii) Physical interpretation of waves for radiation and matter

8. ENERGY LEVELS (probably 1 week)

(a) A discussion of the Franck-Hertz experiment

(i) The energy of atoms increases in discrete steps

(ii) A characteristic set of energy levels exists for each type of atom

(b) Ionization energy

(c) Energy level diagrams

(d) Emission spectra

(i) Discussion of experiments to demonstrate that an excited atom emits photons with energies equal to the differences between energy levels for that atom

(ii) $E_{\text{photon emitted}} = h\nu = E_{\text{initial}} - E_{\text{final}}$

(e) Absorption spectra

(i) Discussion of experiments to demonstrate that an atom absorbs only those photons having energies equal to differences between its permissible energy levels

(ii) $E_{\text{photon absorbed}} = h\nu = E_{\text{final}} - E_{\text{initial}}$

(iii) Photoelectric effect as the absorption of a photon with energy greater than the ionization energy of the atom

9. ENERGY LEVELS OF HYDROGEN (probably ½ week)

(a) Energy levels of atomic hydrogen as determined by experiment

(i) Brief discussion of the results of experiments to determine the energy levels of atomic hydrogen

(ii) Generalization of energy levels for atomic hydrogen as given by

$$E_n = -\frac{13.6}{n^2} \text{ ev (zero at ionization level)}$$

(b) Theoretical derivation of energy levels of atomic hydrogen

(i) Student experiment to study standing waves in a linear medium as a possible aid in developing the new atomic model

(ii) Development of the theoretical equation for the energy levels of atomic hydrogen

(iii) Comparison of the theoretical and experimental equations

TEACHING AIDS AND THEIR USE

It is assumed that there are many sources of reference and assistance which the teacher will investigate for himself. The following contains a few comments on some particularly valuable teaching aids:

THE P.S.S.C. TEXTBOOK

This is a thorough text presenting background information and detailed arguments based on observed experimental data. An insight into scientific investigation and basic concepts is stressed. The student may be encouraged to read relevant passages in advance of the lesson, and possibly to make brief point-form notes on what he considers significant. This preparation will lead to a more meaningful lesson and help him to develop some skill in abstracting key points from a full presentation.

Problem assignments from the textbook should be given with considerable forethought. It may be advisable to supplement the textbook with additional single-concept problems.

The teacher will find a number of areas in this textbook which would be suitable for enrichment of the course. He is advised, however, to study carefully the detailed suggestions concerning the depth of treatment before embarking on the study of additional material.

THE LABORATORY GUIDE

Well in advance of a class experiment the students might read the Laboratory Guide, prepare suitable charts for recording data, and become familiar with the equipment required. In the experiment, opportunity should be given to repeat measurements when time permits. Plotting points on celluloid over graph paper enables a student to watch the progress of a graph and to decide on a reasonable number of measurements. If a china-marking pencil is used, the marks can be erased and the celluloid re-used. In general, the laboratory work should precede the discussion of a concept. Indeed, the post-laboratory lesson can be a fruitful lesson emphasizing the techniques, the limitations of the measurements, and the underlying physical concepts.

The experiments are open-ended in that they invite the student to investigate the problems further. It is essential that the students perform quite a number of experiments themselves. This should not be a teacher-centred demonstration course.

TEACHER'S RESOURCE BOOK AND GUIDE

This set of four volumes is probably the most valuable aid available for a teacher of this course. The function which each unit performs is carefully explained. It integrates the textual material, the problems, laboratory work, films, and the Science Study Series books in order to obtain full advantage of each. Complete solutions are given for the problems and excellent suggestions made in reference to the experiments. It is imperative that teachers have access to the Resource Book and Guide.

SCIENCE STUDY SERIES BOOKS

Numerous titles now are available in this valuable but inexpensive set of reference books. It is suggested that a set of these be available in both library and laboratory, in either hard or soft covers. Since many of these books have been written especially for students of P.S.S.C. Physics, they have a unique place on the reference shelf. It is hoped that the teacher will make frequent reference to material in these interesting books so that students will be encouraged to read and expand their horizons in the field of science.

OBJECTIVE TESTS

The objective tests prepared for the P.S.S.C. Physics course provide a valuable teaching aid, not only as a testing device, but also as a teaching device. The post-test lesson should involve an extremely valuable discussion. Class sets of the tests can be used to advantage at the end of each unit. Because of the differences between Curriculum S.17C (1967) and the P.S.S.C. course, some of the questions on the tests will have to be omitted.

FILMS

This may be the first time that the students have studied a course in which films and film loops perform such a significant function. As the course progresses, the films and loops play an increasingly important role in presentation of the experimental data on which the concepts are based. It is suggested that preference be given to those films which develop ideas that involve equipment not available in the school laboratory. The following list is to serve as a guide; it is not a complete compendium of useful films.

The suggested priority rating consists of three categories: (1) very strongly recommended, (2) highly recommended, (3) recommended. Undoubtedly, there are many other useful films for this course which have not been listed here.

Related Part of the Course	*Film Suggestions*	*Suggested priority*
UNIT I		
1. (a) (i)	PSSC film *Time and Clocks*	3
3.	PSSC film *Straight Line Kinematics* The first half of this film may be used as an introduction. The entire film may be shown after 3(b) as a review. Problems may be assigned on the graphs accompanying the film.	1
4. (f)	ESI film loops *Vector Kinematics*	2
UNIT II		
1.	PSSC film *Introduction to Optics*	1
2. (d) (i)	PSSC film *Pressure of Light*	2
(e) (iii)	PSSC film *Speed of Light*	2
3. (a) (b)	PSSC film *Simple Waves*	3
	Miller Series film loop *Non-Recurrent Wavefronts*	2
4. & 5.	ESI film loops *Ripple Tank Series*	2
6. (a)	Miller Series film loop *Diffraction – Double Slit*	1
(b)	Miller Series film loop *Diffraction – Single Slit*	1

Related Part of the Course	*Film Suggestions*	*Suggested priority*
UNIT III		
	As an introduction, use the PSSC film *Forces*	1
1.	PSSC film *Inertia*	3
	PSSC film *Inertial Mass*	3
	Miller Series film loop *Inertial Forces – Translational Acceleration*	1
2. (b)	PSSC film *Free Fall and Projectile Motion*	3
5. (a)	PSSC film *Energy and Work*	2
(b)	PSSC film *Elastic Collisions and Stored Energy*	1
UNIT IV		
1. (a)	PSSC film *Coulomb's Law*	1
	PSSC film *Electric Lines of Force*	2
	PSSC film *The Millikan Experiment*	1
	PSSC film *The Coulomb Force Constant*	2
2. (c)	PSSC film *Elementary Charges and the Transfer of Kinetic Energy*	2
4.	PSSC film *The Electromagnetic Spectrum*	2
	Miller Series film loop *Absorption Spectra*	2
5.	PSSC film *The Rutherford Atom*	1
6. (a)	PSSC film *Photons*	1
(b)	PSSC film *Interference of Photons*	1
(c)	PSSC film *Photoelectric Effect*	2
7. (a)	PSSC film *Matter Waves*	1
	PSSC film *Frank-Hertz Experiment*	1